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Trace Metal Fate in a Rotary Kiln Incinerator with an Ionizing Wet Scrubber

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16. ABSTRACT

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The test results indicate that cadmium and bismuth were relatively volatile, with an average of less than 40 percent discharged with the kiln ash. Arsenic, barium, chromium, copper, lead, magnesium, and strontium were relatively nonvolatile, with an average of greater than 80 percent discharged with the kiln ash. Observed relative metal volatilities generally agreed with the volatilities predicted based on vapor pressure/temperature relationships, with the exception of arsenic which was much less volatile than predicted. The volatility of cadmium, bismuth, and lead increased as kiln temperature was increased; the discharge distributions of the remaining metals were not significantly affected by changes in kiln temperature. Apparent scrubber collection efficiencies for the metals averaged 22 to 71 percent, and were generally higher for the less volatile metals. The overall average metal collection efficiency was 43 percent.

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INTRODUCTION

The hazardous waste incinerator performance standards, promulgated by EPA in January 1981, established direct particulate and HCl emission limits and mandated 99.99 percent destruction and removal efficiency (DRE) for principal organic hazardous constituents (POHCs). Subsequent risk assessments have suggested that, of the total risk to human health and the environment from (otherwise) properly operated incinerators, hazardous constituent trace metal emissions may pose the largest component. Nevertheless, the data base on trace

metal emissions from incinerators is very sparse. Data on the effects of waste composition and incinerator operation on trace metal emissions are particularly lacking.

In the response to these data needs, an extensive series of tests was conducted at the IRF to investigate the fate of trace metals fed to a rotary kiln incinerator equipped with an IWS for particulate and acid gas control. This program was a continuation of a similar IRF test program (conducted in 1988) that employed a venturi scrubber/packed column scrubber in place of the IWS.

The primary objective of these test programs was to investigate the fate of five hazardous and four nonhazardous trace metals fed to a rotary kiln incinerator in a synthetic solid waste matrix. Of interest was the distribution of the metals as a function of incinerator operating temperatures and feed chlorine content. The hazardous trace metals investigated were arsenic, barium, cadmium, chromium, and lead. The remaining metals were bismuth, copper, magnesium, and strontium.

TEST PROGRAM

The program consisted of nine parametric tests in which the test waste feed contained the nine metals identified above. All tests were conducted in the pilot-scale rotary kiln incinerator system (RKS) at the IRF, illustrated in Figure 1.

Synthetic Test Mixture

The synthetic test waste contained a mixture of organic liquids added to a clay absorbent material. Trace metals were incorporated by spiking an aqueous mixture of the metals of interest onto the organic liquid-containing solid material. The synthetic waste was fed to the rotary kiln via a twin-auger screw feeder at a nominal rate of 63 kg/hr (140 lb/hr).

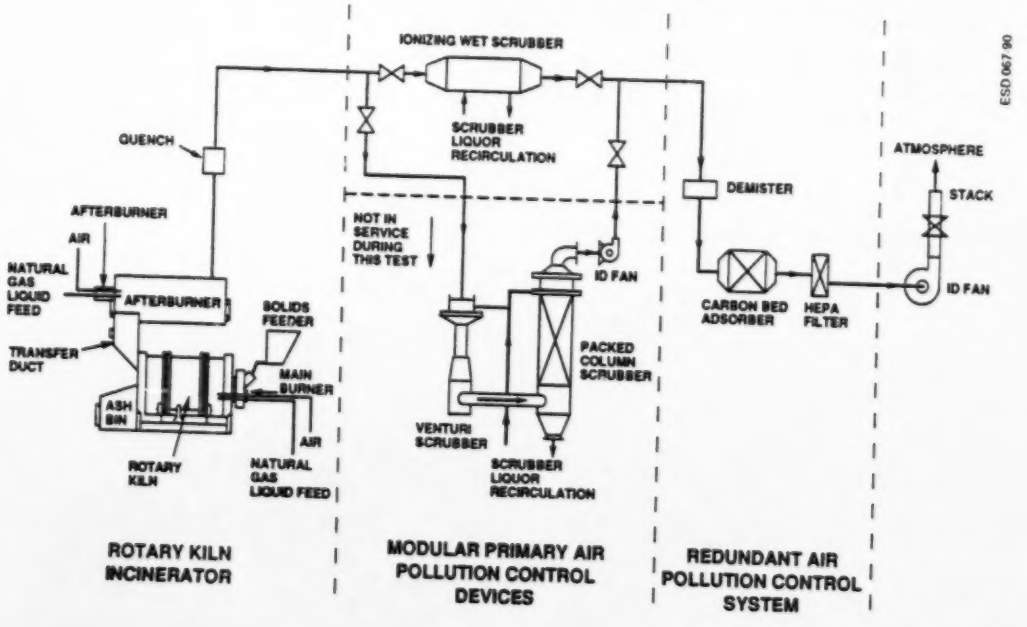

Figure 1. Schematic of the IRF rotary kiln incineration system.

The organic liquid base consisted of toluene, with varying amounts of tetrachloroethylene and chlorobenzene added to provide a range of chlorine contents. Synthetic waste chlorine was varied from 0 to nominally 8 percent. The analyzed organic fractions for the three waste feed mixtures are given in Table 1. Table 2 summarizes the average metal concentrations in the combined waste feed over the nine tests.

Test Conditions

The test variables were kiln temperature, afterburner temperature, and the chlorine content of the synthetic waste feed. Seven specific combinations of these variables were selected as test points. Target and average achieved values for these three variables are summarized in Table 3. For all tests, excess air was nominally 11.5 and 7.5 percent oxygen in the kiln and the afterburner exit flue gas, respectively. Estimated solids residence time within the kiln was about one hour. Figure 2 identifies the sampling locations for the tests. Flue gas samples were also collected at the stack for evaluating hazardous waste management permit compliance.

TEST RESULTS

Average Trace Metal Discharge Distributions

Figure 3 shows the amounts of metal found in each discharge stream, as a fraction of the total found in the three discharge streams—kiln ash, scrubber exit flue gas, and scrubber liquor. In Figure 3, the bar for each metal represents the range in the fraction accounted for by each discharge stream over all nine tests, with the average fraction from all tests noted by the midrange tick mark. Metal discharge distribution data in Figure 3 are plotted versus the metals'

TABLE 1. POHC CONCENTRATIONS IN CLAY/ORGANIC LIQUID FEED

Test	Weight % in mixture			
	Toluene	Tetrachloroethylene	Chlorobenzene	Chlorine content[a]
1	23.1	0	0	0
2 through 8 (average)	17.8	3.1	3.0	3.6
9	11.6	6.0	5.6	6.9

[a]Calculated based on measured tetrachloroethylene and chlorobenzene concentrations.

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TABLE 2. AVERAGE INTEGRATED FEED METAL CONCENTRATIONS

Metal	Concentration (mg/kg)	Metal	Concentration (mg/kg)
Arsenic	48	Copper	380
Barium	390	Lead	45
Bismuth	330	Magnesium	18,800
Cadmium	10	Strontium	410
Chromium	40		

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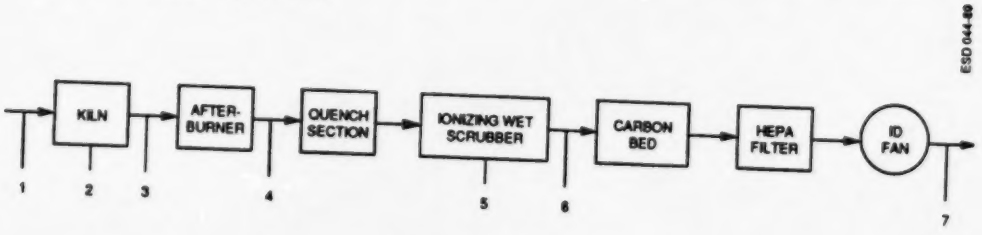
TABLE 3. TARGET AND AVERAGE ACHIEVED TEST CONDITIONS

Test	Date	Feed mixture Cl content (%)		Kiln exit temperature °C (°F)		Afterburner exit temperature °C (°F)	
		Target	Actual	Target	Average	Target	Average
1	8/17/89	0	0	871 (1600)	900 (1652)	1093 (2000)	1088 (1990)
2	8/2/89	4	3.5	815 (1500)	819 (1507)	1093 (2000)	1095 (2002)
3	8/4/89	4	3.5	927 (1700)	929 (1704)	1093 (2000)	1092 (1998)
4	8/1/89	4	3.5	871 (1600)	877 (1610)	1093 (2000)	1096 (2006)
5	8/16/89	4	3.7	871 (1600)	885 (1625)	1204 (2200)	1163 (2125)
6	8/15/89	4	3.6	871 (1600)	887 (1629)	982 (1800)	1017 (1863)
7[a]	8/9/89	4	3.6	871 (1600)	881 (1618)	1093 (2000)	1103 (2018)
8[a]	8/11/89	4	3.8	871 (1600)	879 (1615)	1093 (2000)	1098 (2008)
9	7/28/89	8	6.9	871 (1600)	881 (1617)	1093 (2000)	1087 (1988)

[a] Test points 7 and 8 are replicates of test point 4; together the three tests provided the components of an IRF trial burn.



SAMPLE LOCATIONS

Sampling point	Feeds and residuals				Continuous monitors				Flue gas			
	Clay/organic liquid	Metal spike solution	Kiln ash	Scrubber blowdown	O_2	CO, CO_2	NO_x	Unheated THC	Method 17 with multiple metal impingers (particulate, metals, and HCl)	Method 5 with multiple metals impingers (particulate, metals, and HCl)	VOST (volatile organics)	Method 5 (particulate and HCl)
1	X	X										
2			X									
3					X							
4					X	X		X	X		X	
5				X								
6					X		X	X		X	X	
7					X	X		X			X[a]	X

[a] Tests 4, 7, and 8 only.

Figure 2. Sampling protocol.

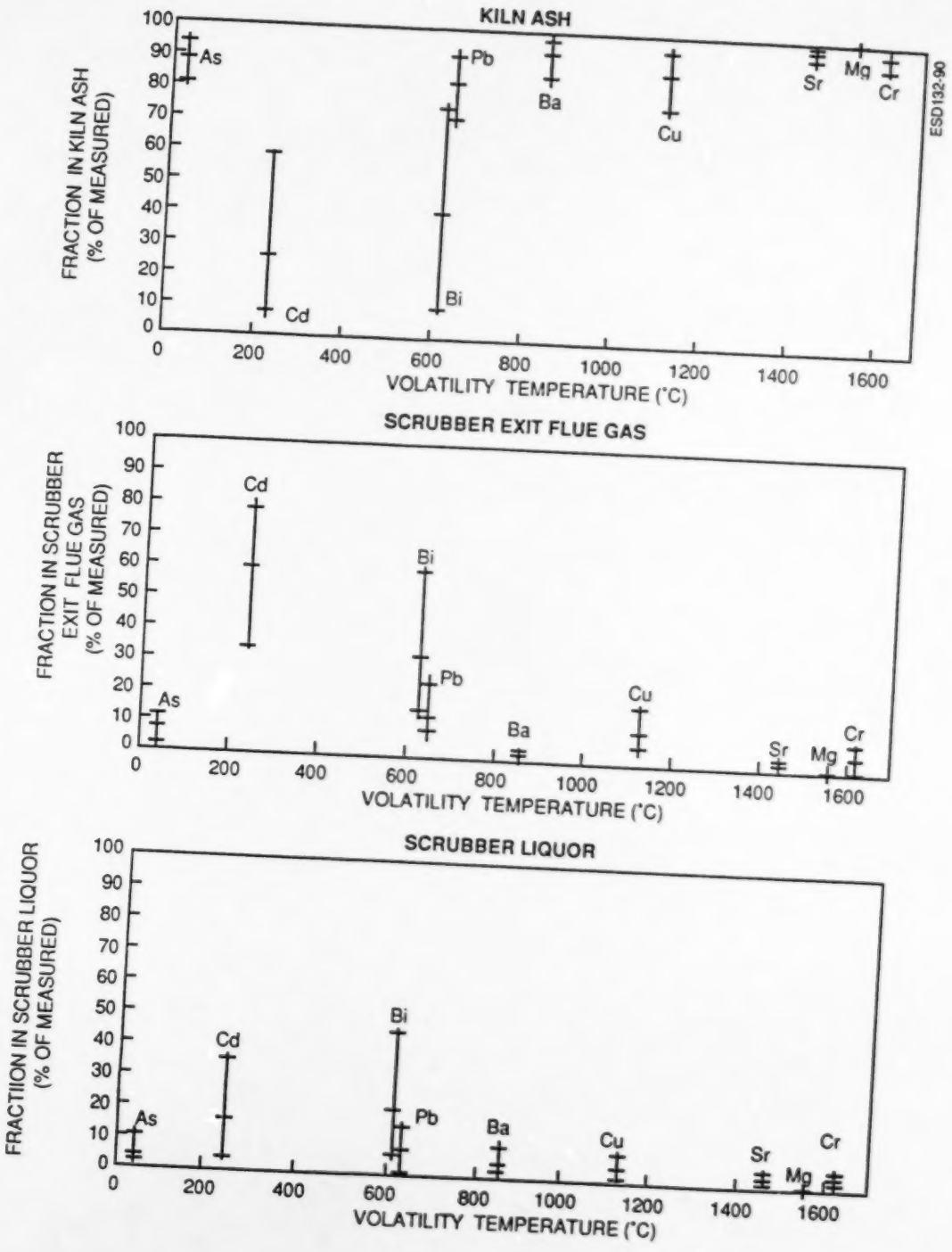


Figure 3. Distribution of metals in the discharge streams.

volatility temperatures (the temperature at which the vapor pressure of the most volatile principal species of each metal under oxidizing conditions is 10^{-6} atm). The lower the volatility temperature, the more volatile the metal is expected to be.

Figure 3 indicates a correlation between observed volatility and volatility temperature for all the metals tested, except arsenic. With the exception of arsenic, average normalized kiln ash fraction increased more or less directly with increasing volatility temperature. Cadmium and bismuth were relatively volatile and were less prevalent in the kiln ash than were the more refractory metals (arsenic, lead, barium, copper, strontium, magnesium, and chromium). Kiln ash fractions accounted for the majority of these metals.

Based on volatility temperature, arsenic is expected to be the most volatile element. However, the data show arsenic to be apparently refractory, remaining largely with the kiln ash. The volatility temperature for arsenic is based on the vapor pressure of As_2O_3. The fact that arsenic is significantly less volatile than expected (were As_2O_3 the predominant arsenic species) suggests that either some other, less volatile arsenic compound (perhaps an arsenate) was preferred, or that some other chemical interaction such as strong adsorption to the clay occurred.

Effects of Incinerator Operating Conditions on Metal Distributions

Increased kiln temperature caused a noticeable increase in the volatility of cadmium, bismuth, and lead. Figure 4 shows that as the kiln temperature increased there was a significant decrease in the kiln ash fraction of these metals, with corresponding increases in the scrubber exit flue gas and scrubber liquor fractions. Although the volatility of lead increased with higher kiln temperature, lead still remained relatively refractory and was found primarily in the kiln ash. Kiln temperature within the tested range had no significant effect on the discharge distributions of any of the remaining metals.

Afterburner temperatures within the tested range did not clearly affect the distributions of any of the metals among the scrubber exit flue gas and scrubber liquor discharge streams. Data on the effect of feed chlorine content are inconclusive pending investigation of an apparent relationship between feed chlorine and the efficiency of the analytical procedure for metals in kiln ash.

Apparent Scrubber Collection Efficiencies

The apparent scrubber efficiency for collecting flue gas metals was determined for each test. The apparent scrubber efficiency represents the ratio of the normalized metal fraction measured in the scrubber liquor to the sum of the normalized metal fractions measured in the scrubber liquor and scrubber exit flue gas. Figure 5 summarizes the efficiency data. The bar for each metal represents the range of scrubber efficiencies over the nine tests, with the overall average for the nine tests noted by the midrange tick mark. Average metal collection efficiencies ranged from 22 to 71 percent; the overall average for all metals was 43 percent. Figure 5 shows that there were significant variations in the efficiencies for each metal. However, average efficiencies generally increased with increased metal volatility temperatures.

CONCLUSIONS

Test conclusions include the following:

- Cadmium and bismuth were relatively volatile, with an average of less than 40 percent of the discharged metal accounted for by the kiln ash. Arsenic, barium,

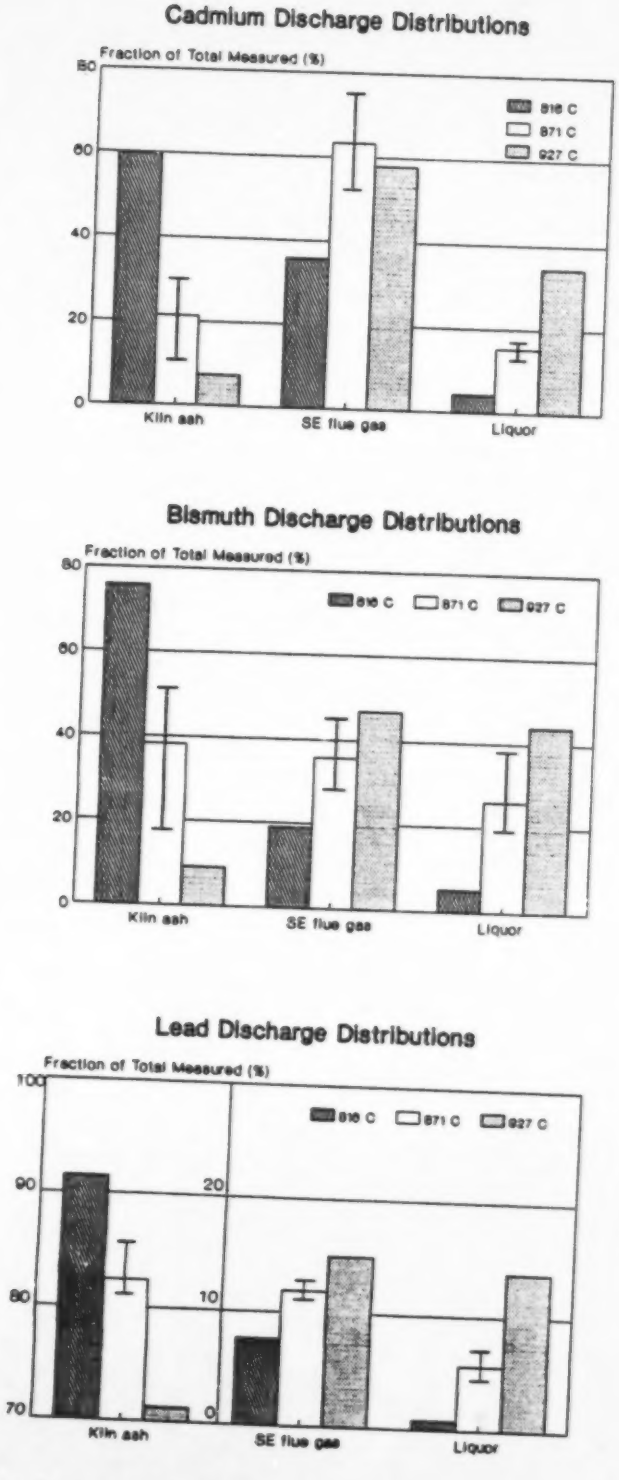


Figure 4. Effects of kiln temperature on the discharge distributions of cadmium, bismuth, and lead.

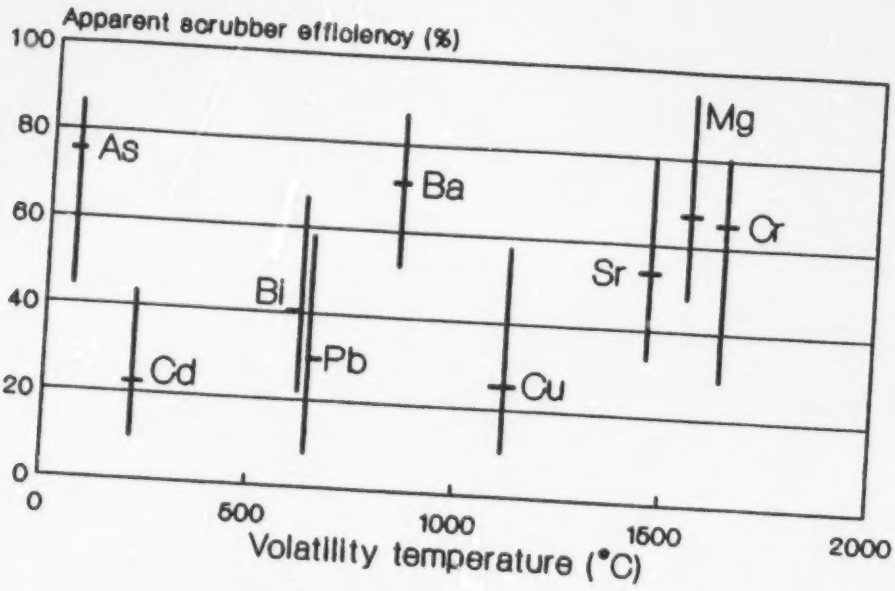


Figure 5. IWS apparent collection efficiencies for metals.

chromium, copper, lead, magnesium, and strontium were relatively nonvolatile, with an average of greater than 80 percent of the discharged metal accounted for by the kiln ash.

- Observed metal volatilities generally agreed with the order predicted by metal volatility temperatures, with the notable exception of arsenic. Arsenic has the lowest volatility temperature of the metals tested, but was observed to be one of the least volatile of the metals. This suggests that As_2O_3 was not the predominant arsenic species in the incinerator, or that the arsenic is adsorbed by the clay/ash matrix.

- Kiln temperature affected the relative volatility of cadmium, bismuth, and lead. The fraction of metal discharged in the kiln ash decreased with increasing kiln temperature.

- Afterburner exit temperature did not clearly affect metal partitioning among the scrubber exit flue gas and scrubber liquor discharge streams.

- The average apparent scrubber collection efficiencies for metals ranged from 22 to 71 percent, and generally increased with decreasing metal volatility. The overall average collection efficiency for all metals was 43 percent.